MS-I

NASA S-1C 2219-T37 GORE SECTION

EXPLOSIVE FORMING DEVELOPMENT PROGRAM

Summary of Phase II - Sub-Scale Explosive Forming

RYAN

AERONAUTICAL COMPANY

REPORT NO. 64B079A

5 JUNE 1964

NASA S-1C 2219-T37 GORE SECTION

EXPLOSIVE FORMING DEVELOPMENT PROGRAM

Summary of Phase II - Sub-Scale Explosive Forming

References:
NASA Contract No. 8-5129
Ryan Report Nos.
63B093
63B137
64B080A

RYAN
AERONAUTICAL COMPANY

REPORT NO. 64B079A
5 JUNE 1964

25 PAGES

COPY NO.________

FOREWORD

This report covers the second phase of a Research and Development Program to determine optimum forming, tool design, and manufacturing processes for 2219-T37 gore segments for The National Aeronautics and Space Administration, George C. Marshall Space Flight Center, Huntsville, Alabama. The program was administered for NASA by P. H. Schuerer, J. R. Williams and L. A. Bowers.

Ryan personnel who conducted the research were P. E. Olivas, Tool Engineering, and R. A. Chase, Production.

Prepared by: ______________________
H. F. Wallen
Chief Tool Engineer

Approved by: ______________________
K. D. Hawkins
Chief, Manufacturing
Technical Development

ABSTRACT

29225

Objective of this second phase of a three-phase program was to further prove the gripping ability of the two clamps recommended during the first phase. (See Report No. MR-63-16, Material and Process Laboratories Metallurgical Report, "Evaluation of Explosive Forming Gripping Jaws".) First, 4-inch wide clamps were used during the first phase to run tests in the 2' x 4' sub-scale explosive form die. The self-energizing clamp was eliminated because the adjustment of the gripping angle was too critical to be practical under production conditions. Then, four stretch-press type clamps 13 inches long were made and evaluated, and proved to have adequate gripping power to elongate the .800" 2219-T37 aluminum 2-1/2 to 3 percent. The gripping of all clamps was uniform enough under explosive conditions to prevent failure due to local overloading.

Full scale tests, using lead shims that were added to the edges of the base gore die, proved the validity of balancing the elongation so that the edge material drew into the die more uniformly. Preliminary information was gained by mounting the four clamps from the sub-scale die at center points on each side of the base die. From this data, it was decided to add five stretch press type clamps to the apex die, and nine to the base die.

There was evidence that air bubbles were being trapped between the part and the die causing flat spots in the part. This will be eliminated by better venting to the vacuum source and staging the forming.

Technical data on relative stress wave propagation and reflection in typical explosive forming materials was generated during this phase and is available in Ryan Report No. 64B021. Instruments for recording stress data were tried on one of the jury-rigged shots and proved successful to be used on Phase III.

Author

RYAN 64B079

CONTENTS

LIST OF FIGURES

OBJECTIVES

Phase II consists of two studies. The first utilized a sub-scale die (Figure 1) to continue studies of clamp types and the second made use of the full scale base die to see if balancing the required elongation were feasible.

The purpose of the sub-scale die research was to select the best clamp configuration in order to restrain the material without fracturing it. Based on the results from Phase I, the stretch press clamp (Figure 2) and the self-energizing clamp (Figure 3) were studied under explosive conditions in order to select the better clamp. Because of schedule urgency, preliminary tests were run using the 4-inch wide clamps made for the Phase I study.

Four stretch press clamps 13 inches wide were fabricated to further prove:

1. Several clamps can be used in tandem, gripping the material with sufficient uniformity to prevent fracturing of the part due to local overloading.

2. The jaws can be designed to grip the material without causing stress riser at which rupture would occur.

3. These clamps have sufficient holding force to elongate .800" 2219-T37 aluminum at least 2 to 3 percent.

4. The energizing wedge can preload the clamp jaws enough to prevent slippage and still be unloaded after the forming operation is completed.

The purpose of full scale jury-rig research was to obtain preliminary data on charge magnitude, configuration, and standoff; shims required to balance elongation; and holding capabilities of the draw ring under 60-ton pressure per C clamp.

GENERAL DESCRIPTION OF PROCEDURE AND EQUIPMENT

SUB-SCALE TESTS

Procedure:

The following general procedure applies to all sub-scale die tests.

Material was 24" x 48" 2219-T37 aluminum .800" thick. The 24" dimension was machined to $^{+.000}_{-.060}$ so that it passed freely into the die cavity. The .800" thickness was based on the maximum known requirement.

Elongation marks at 2.000" intervals were scribed across the center lines between clamps. Readings were made with 6" scale and are accurate to .005.

Vacuum seal was achieved by use of zinc chromate and duct seal in conjunction with the rubber seals provided on the die.

Charge magnitude was calculated, per reference "Report on Explosive Forming Technical Data Ryan Report No. 64B001," using PETN Primacord. Clamp faces were protected from the full impact of the shock wave by foam blocks. Foam was a minimum of 4 inches thick and disintegrated during the shot.

Basic Equipment:

Tank used was 10 feet in diameter and provided approximately 4 feet of water head.

Sub-scale Die shown in Figure 1 has a 3T (2.4") radii and a 4T (3.2") radii over which, the metal forms.

The 4-inch stretch press clamp is shown in Figure 2. A cross wedge similar to one that is shown in Figure 4 was substituted for the energizing screw.

The 4-inch self-energizing clamp used is shown in Figure 3.

The 13-inch clamps are shown in Figure 4 along with jaw and wedge terminology.

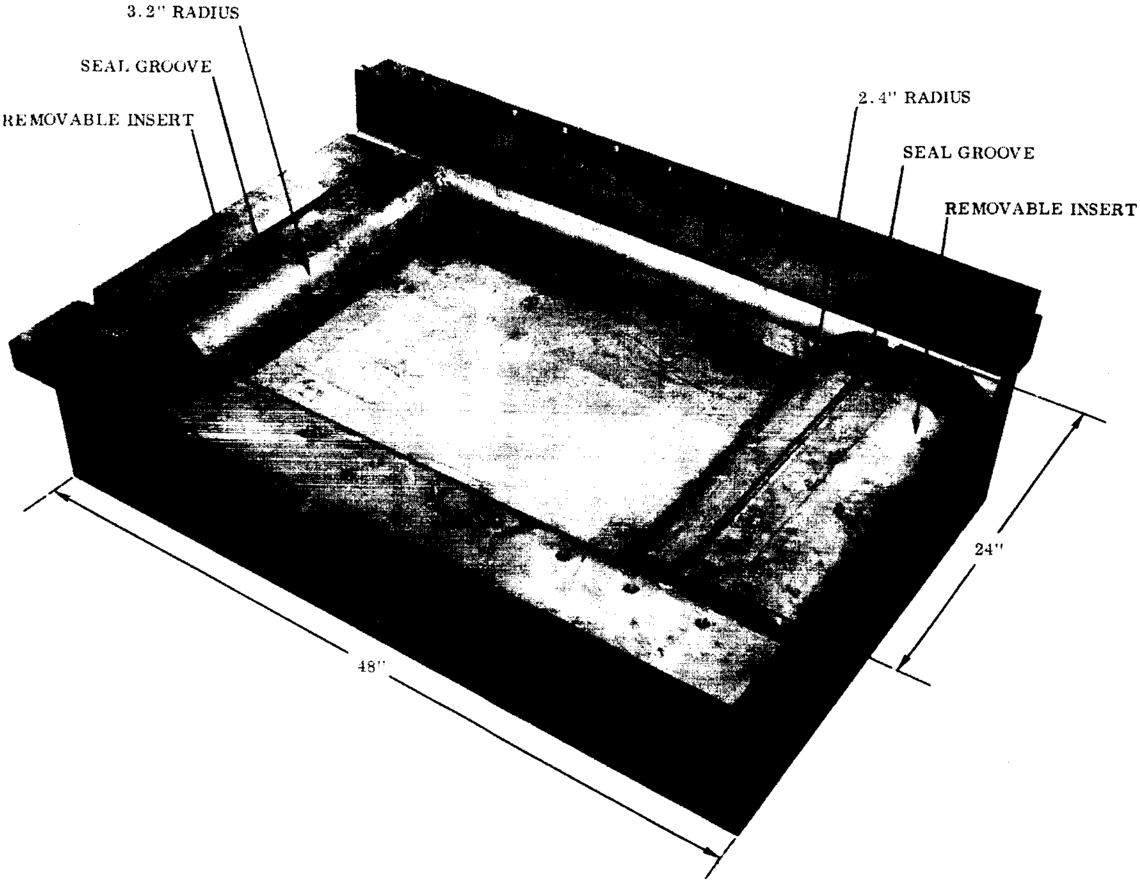


Figure 1 Sub-Scale Die

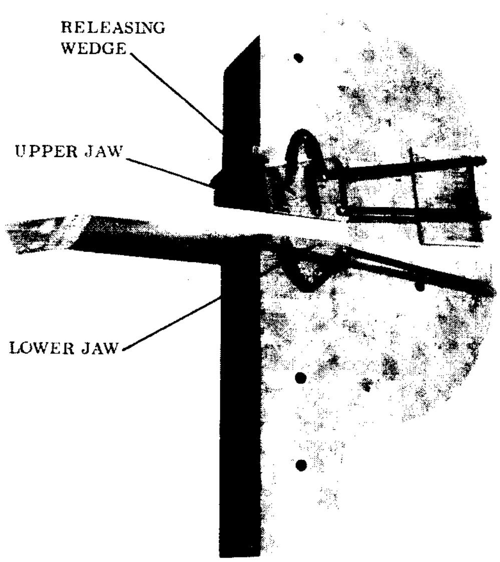


Figure 2 Stretch Press Type Clamp

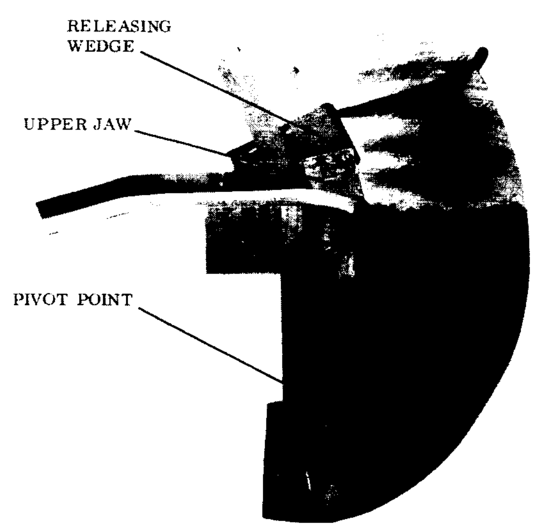


Figure 3 Self-Energizing Clamp

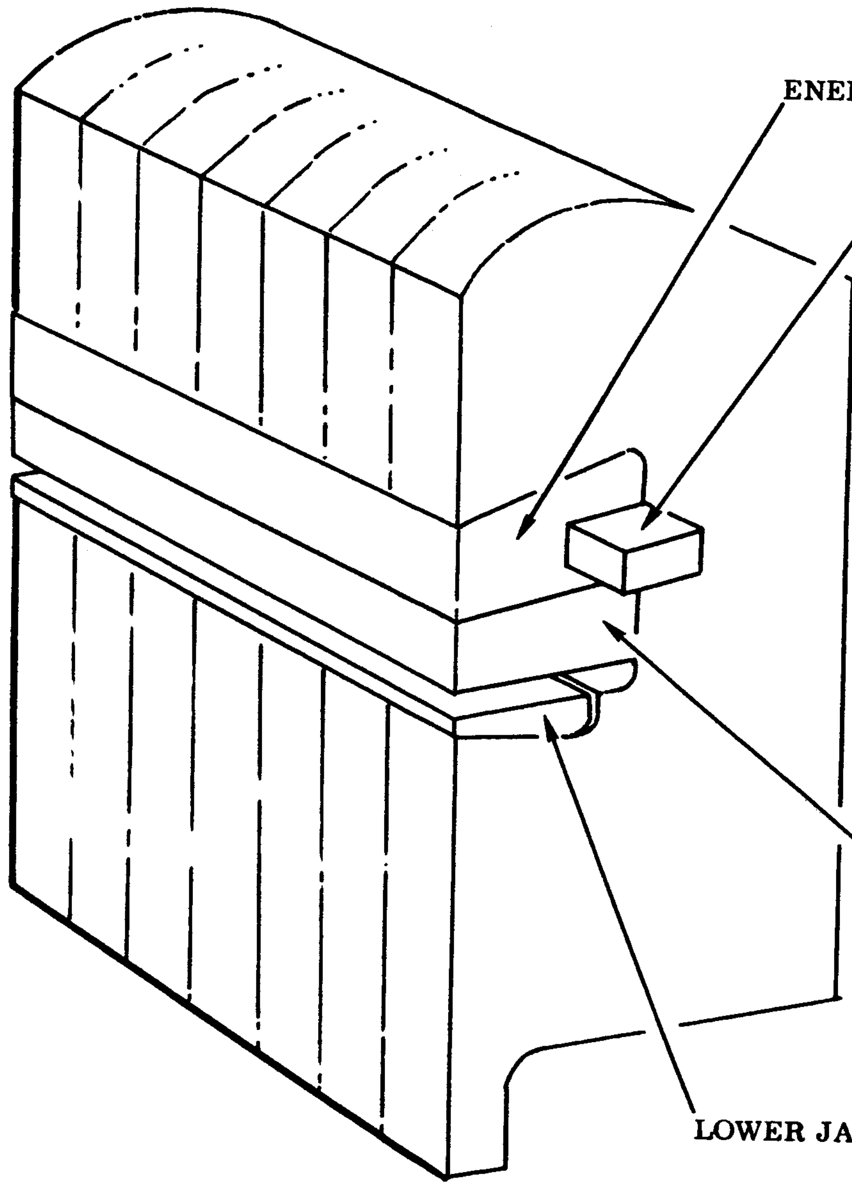


Figure 4 13-Inch Stretch Press Type Clamp

FULL SCALE JURY-RIGGED TESTS

Procedure:

The general approach to the preliminary full scale tests was as follows:

Material formed was 2219-T37 aluminum in .297" to .661" thickness. Tapered lead shims 6 inches wide were added to the edge of the die. The shim configuration was based on a study that showed the contour of the die was not deep enough in most areas to exceed the yield of the material during forming. Shims (Figure 6) were designed to bring the elongation along each grid line up to 2 to 3 percent over the entire area of the tool.

Gripping of the material between the draw ring and the die was increased by the use of double-faced emory paper, as indicated by the results from Phase I. C clamps were beefed-up to withstand 60 tons of pressure. The number was increased to 30.

Elongation checks were made using a 10-inch grid scribed over the entire part. Average percent comparisons between blanks are based on readings taken along the transverse center line between the clamps on the sides. For calculation of charge size refer to Phase I, Report No. 64B001, "Report of Explosive Forming Technical Data", and data gathered progressively during Phase II as covered in Report No. 64B021. The charge configuration was based on discussion with Martin-Denver which indicated that the standoff should be in the order of 10 to 12 inches, and that the distance between Primacords should be twice the standoff. Foam blocks were used to protect the face of the draw ring.

Vacuum seal was achieved using zinc chromate backed up by duct seal.

Equipment:

Water head of 6 to 8 feet was provided by use of the 25-inch diameter tank.

The base die used for the jury-rigged test is shown in Figure 5. The draw ring with C clamps is in place. The charge is being rigged and the protective foam may be seen attached to the face of the ring.

Lead shims - a close-up of the lead shims is illustrated in Figure 6. The lower shim is attached to the die, and the upper to the draw ring.

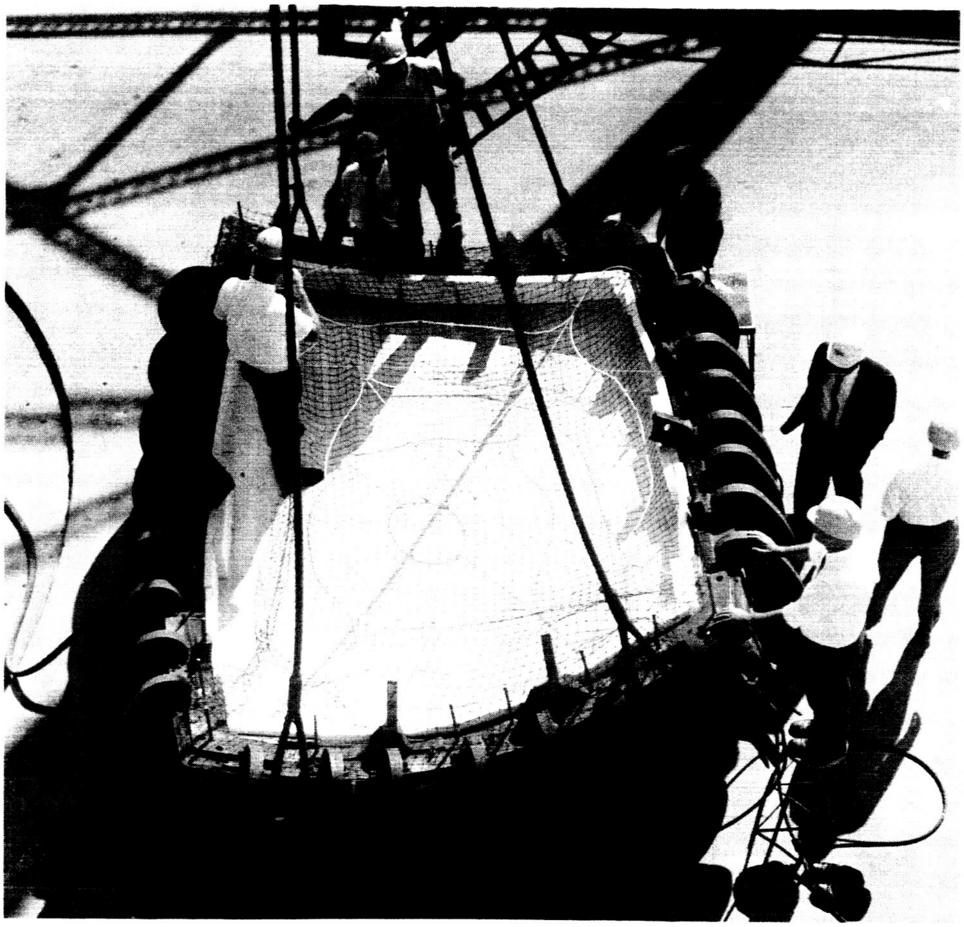


Figure 5 Base Die Used For Jury-Rigged Tests

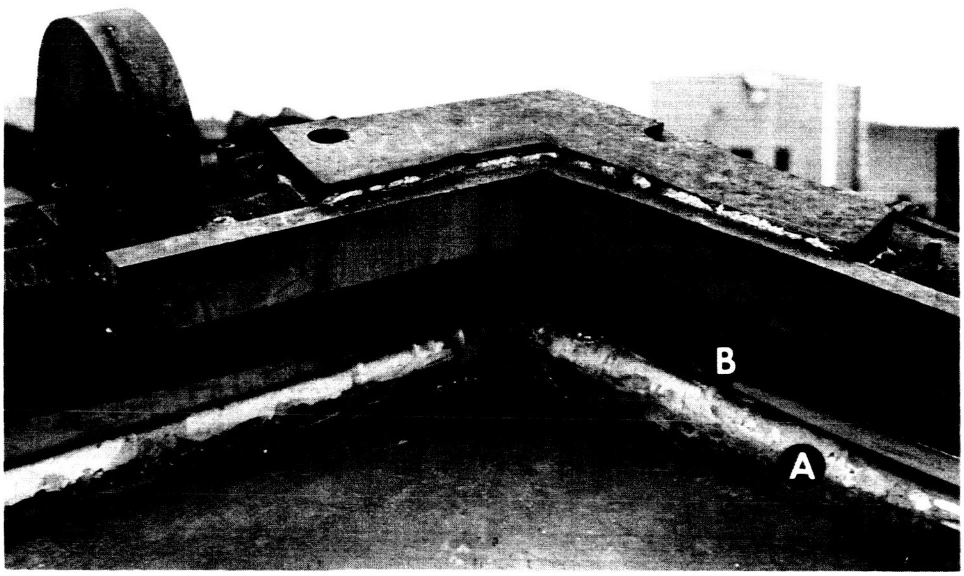


Figure 6 Lead Shims as Viewed in Corner of Base Die

BRIEF DESCRIPTION OF INDIVIDUAL SUBSCALE TESTS

TEST NO. 1

OBJECTIVE

To test this type of clamp under explosive forming conditions and to obtain preliminary data using the 4-inch laboratory stretch press clamp from Phase I, while the 13-inch clamps were being completed.

DESCRIPTION

4-Inch Clamp - jaw angle was 7-1/2° with the gripping surfaces sand blasted. The angle of the energizing wedge was 10° and the cross wedge was 7-1/2°.

Sub-Scale Test Die - (See Figure 1.)

Material -.800" x 24" x 48" 2219-T37 aluminum cut down to 4 inches as shown in Figure 7.

Explosive - PETN Primacord 1500 grains, in one bundle 18 inches long consisting of two 400-grain and one 200-grain pieces.

PROCEDURE

Loading - the part was loaded into the 4-inch stretch press jaw which was energized by means of an impact tool. The opposite end of the part was held by nine 3/4-inch dowels and three 3/4-inch Allen bolts.

Vacuum - no leakage at 28 inches of mercury.

Charge - the explosive was placed on the transverse centerline with 9 inches standoff and was detonated by a single cap.

Water Head - approximately 6 feet.

RESULTS

Jaws - the upper jaw failed to energize allowing the lower jaw to pull too far forward (Figure 8).

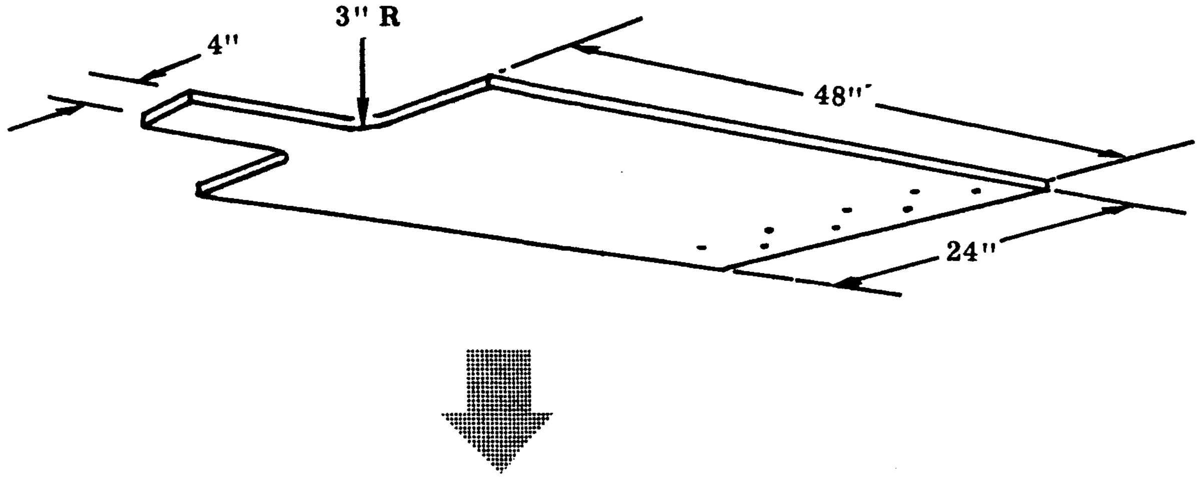


Figure 7 Aluminum Blank Configuration for Sub-Scale Tests 1 and 2, 2219 T37 .800 Inches Thick

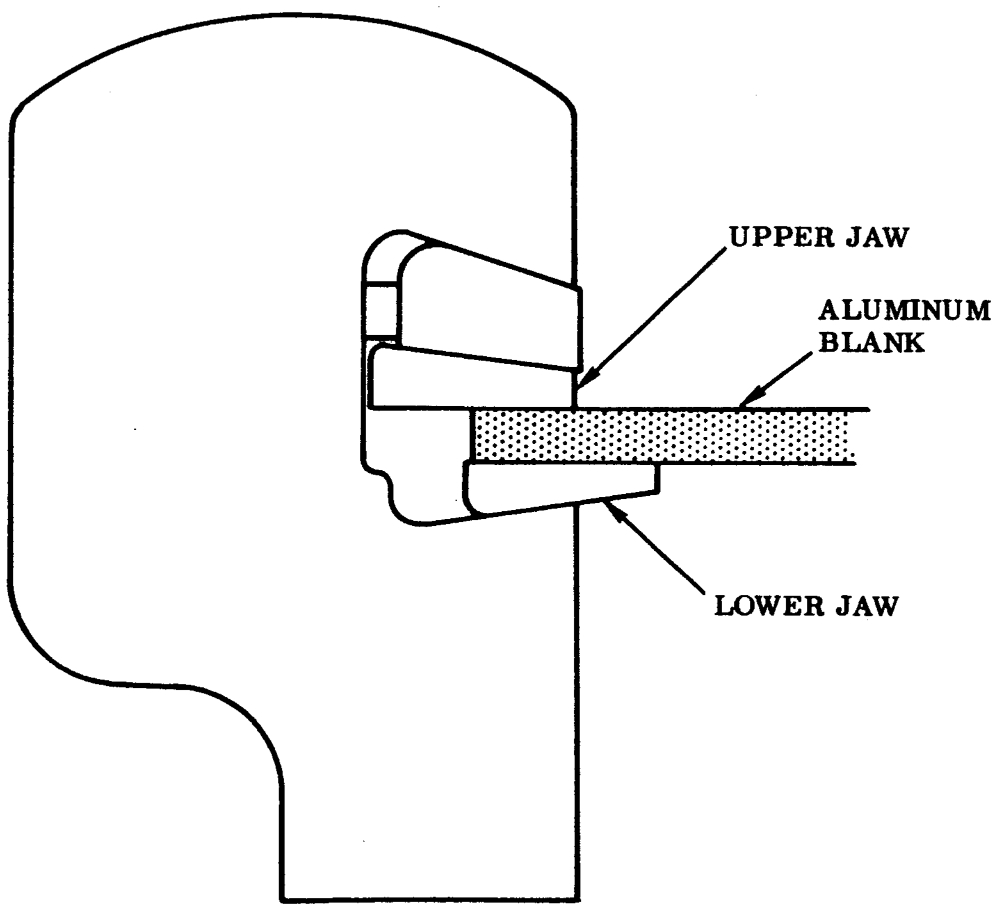


Figure 8 Jaw Failure on Test No. 1

TEST NO. 1 (Continued)

Unloading - The cross wedge and energizing wedge tapped back satisfactorily, however, this did not allow enough jaw opening to unload the part. The lower jaw was bent where it extended beyond the clamp. The sand blasted surface of both jaws was smooth.

Elongation - none that could not be attributed to simple bending.

Form - A single bend in the center.

ANALYSIS

The seal rubber across the 24-inch width over-loaded the 4-inch tongue causing it to bow, which made the rear edge of the lower jaw indent into the aluminum. This forced the lower jaw to energize, but held the upper back. A single charge caused a single bend which does not require enough movement of the material to both energize the clamps and elongate the material.

RECOMMENDATION

The jaws should be knurled or serrated to guarantee enough grip to cause them to energize.

Two bundles of Primacord should be used to assure adequate elongation.

TEST NO. 2

OBJECTIVE

To obtain preliminary data using the 4-inch self-energizing clamp from Phase I so that it could be compared to the stretch-press type clamp under explosive forming conditions.

DESCRIPTION

Clamp - Self-energizing type clamp jaws roughened but not knurled (Figure 3).

Material - .300" x 24" x 48" 2219- T37 aluminum blank with 4-inch tongue (see Test No. 1, Figure 7).

Explosive - PETN Primacord 3000 grains in two bundles 18 inches long of two 400-grain and one 200-grain pieces. Two caps were used.

TEST NO. 2 (Continued)

PROCEDURE

Jaws - the blank was loaded into the 4-inch jaw which was pre-energized by two 1/2-inch diameter Allen screws. The opposite end of the material was held per Test No. 1.

Vacuum - zinc chromate and duct seal were used as sealants. A poor seal was achieved due to small cracks in the Devcon filler inside the die. Vacuum was only 21 inches of Mercury.

Charge - the charges were placed symmetrically about the transverse centerline 18 inches apart with a 9-inch standoff, with adequate foam protection for the clamp (Figure 9).

Water Head - approximately 6 feet.

RESULTS

Clamping - the clamp failed to energize, allowing the material to slip forward, reforming as it moved.

Unloading - the de-energizing wedge retracted satisfactorily.

Elongation - none that could not be attributed to simple bending.

Charge - one bundle failed to fire due to poor electrical contact to the cap. The resulting single bend did not cause enough movement of the metal to elongate the material.

ANALYSIS

Although the results were made somewhat inconclusive by the failure of the charge, it is evident that this clamp is impractical for production use. Knurling of the jaw and application of more pre-energizing force would undoubtedly help. However, the inertia of the clamp, the critical adjustment of the clamp angle, and jaw position make this clamp too hard to handle.

RECOMMENDATION

The adjustment of this clamp is too sensitive for production use, therefore, it should be dropped in favor of the stretch press clamp.

TEST NO. 3

OBJECTIVE

To test the ability of several stretch press clamps to grip uniformly enough so that the material would not fracture due to uneven loading. Also, to prove that the serrations do not cause failure because of stretch risers.

DESCRIPTION

Clamps - four 13-inch clamps with jaws serrated .020" deep for the forward 2/3 of the jaw area, and .030" deep for the last 1/3. Spacing .050" and .080" between center respectively. Angles were jaws 7-1/2° each, energizing wedge 10°, and cross wedge 7-1/2°.

Material - .847" x 24" x 54" 2219-T37 aluminum.

Explosive - 4800 grains in two bundles 18 inches long of 4 x 400 grains each. Two caps.

PROCEDURE

Loading - material was bowed making it difficult to load into the jaws. Clamps 3 and 4 were energized using a 3/8 inch puller bolt on the cross wedge. Clamps 1 and 2 had additional force applied to the cross wedge by use of a crow bar.

Vacuum - poor. 26.2 inches of mercury.

Charge - placed symmetrically about the transverse centerline 18 inches apart with a 9-inch standoff.

RESULTS

Jaws - 1 and 2 held and 3 and 4 slipped canting forward at the centerline. (Figure 10).

Elongation - average .5 to 1 percent was taken only in the flat area along the bottom of the die to simulate a trimmed part.

Form - good at clamps 1 and 2. Flat where it had bottomed on the die. The Ogee curve at clamps 3 and 4 was not well defined.

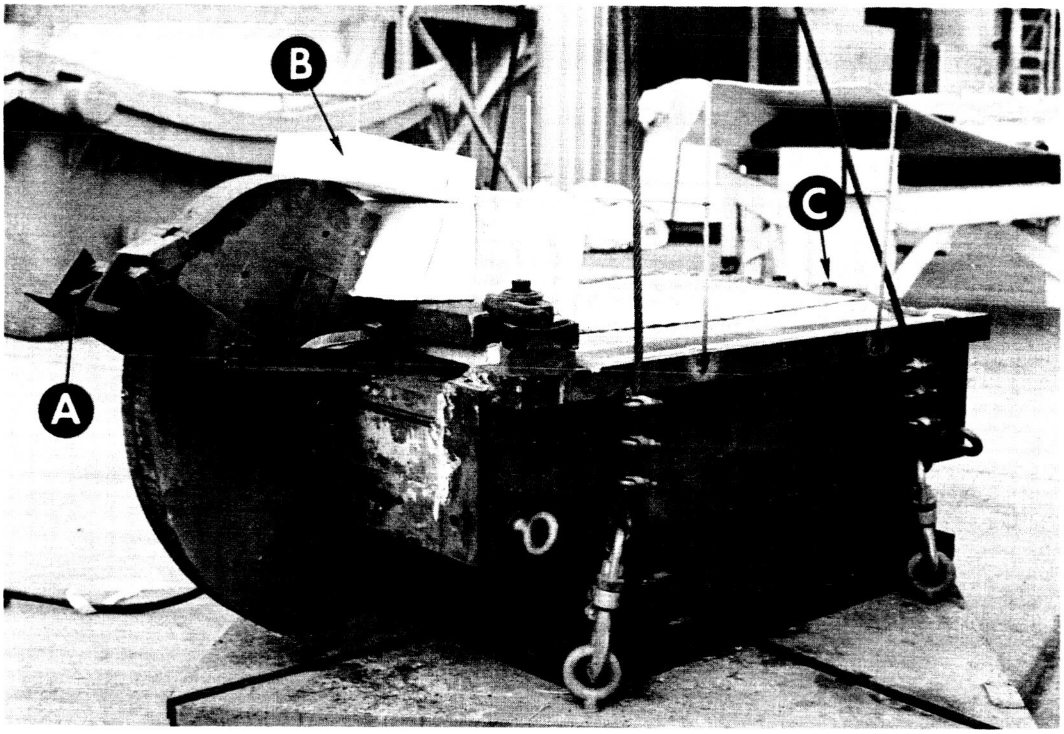


Figure 9 Sub-Scale Die and Full Size Self-Energizing Clamp. Pre-energizing Screw, A; Foam Blocks, B; and Material Securing Bolts, C.

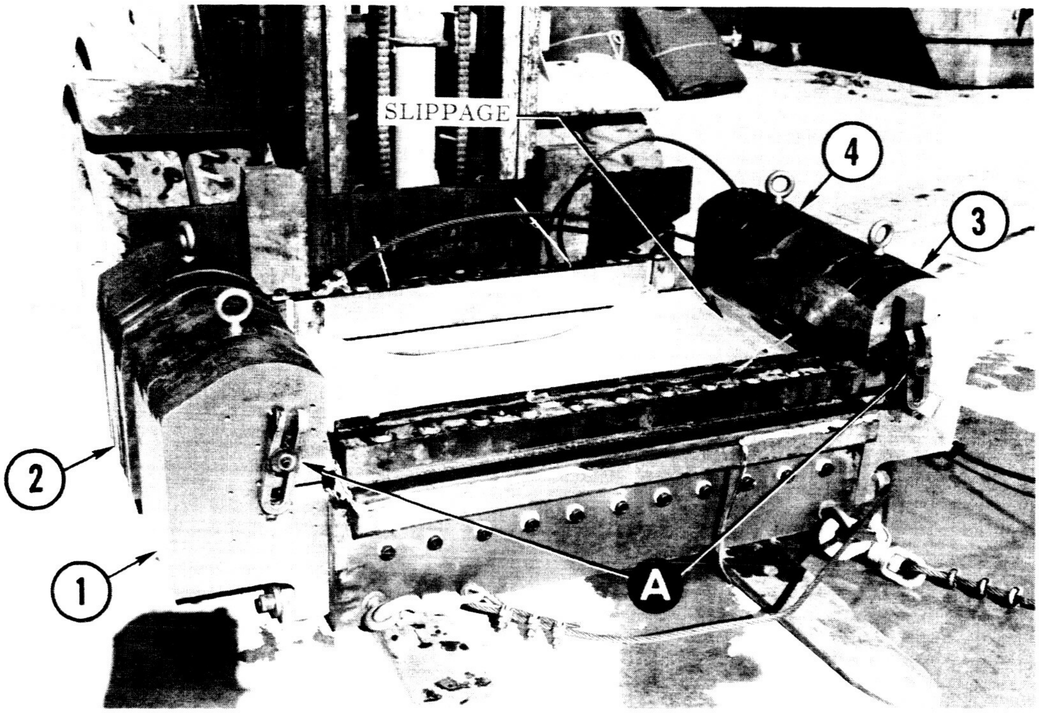


Figure 10 Sub-Scale Die and Partially Formed Part Showing Clamps 1, 2, 3, 4 and Transverse Tie Bolts, A

Unloading - The cross wedge released under a hard blow from a lead hammer. The energizing wedge also tapped back without any problem. There was not enough jaw gap for easy unloading.

ANALYSIS

3/8-inch bolt is not adequate for energizing. More travel of the wedges is required. Serrations are good.

RECOMMENDATION

Crowbar should be used to energize the clamps on future tests. Smaller angle on the cross wedge is indicated. More clearance is required for production. A rubber pad should be used to improve sealing.

TEST NO. 4

OBJECTIVE

To determine whether explosive forming is primarily a result of dynamic energizing of the part. To see whether forming and/or planishing occur if the part does not move relative to the die.

DESCRIPTION

Material - .500" x 18" x 22" 2219-T37 aluminum plate.

Explosive - 3600 grains of PETN Primacord in one 18-inch bundle of 6 x 400 grain pieces.

PROCEDURE

Check - flatness was checked and recorded.

Loading - the flat plate was sealed and taped tight against the bottom of the sub-scale die. A thin plastic vinyl sheet was used to help seal.

Vacuum - the line that evacuated leaked so that a gauge reading of only 26 inches of mercury was obtained. However, no water had remained between the part and the die.

Explosive - the charge was placed lengthwise along the part centerline with 9 inches standoff.

RESULTS

Part was .021" out of flat, both before and after the test, showing absolutely no change. There was no evidence of planishing. The plastic completely disintegrated.

ANALYSIS

No forming occurs unless the part is thrown against the die.

TEST NO. 5

OBJECTIVE

Same as Test No. 3. An added purpose was to see if energizing could be improved to give consistent holding and still release for unloading.

DESCRIPTION

Clamps - same as Test No. 3 except that the cross wedge angle was changed from 7-1/2° to 5°.

Material - .796" x 23-3/4" x 54-3/4" 2219-T37 aluminum plate.

Explosive - 6000 grains of PETN Primacord, two bundles 5 x 400 grains each.

PROCEDURE

Material - was machined flat and smooth.

Loading - clamps were energized using a 5-foot pry bar and locked in place by 3/8 inch Allen bolt.

Vacuum - seal was excellent at 28-3/4 inches of mercury.

Explosive - the charges were symmetrically placed 18 inches apart across the centerline.

RESULTS

Form was fair and within 1/2 inch of the bottom of the die. Ogee curves were not down to the die, especially between clamps 3 and 4.

Clamps - energized and held (Figure 11).

Elongation - .68% and 1.35% over flat areas that would simulate a trimmed part (Figure 12).

RECOMMENDATION

Since the clamps held, another shot should be made without unloading the part to finish forming and sharpen-up the Ogee radii.

SHOT NO. 2

PROCEDURE

Loading - the part was re-sealed without unloading or loosening clamps.

Vacuum - was excellent. 29 inches of mercury.

Charge - 1 pound, 1400 grains of Primacord in two 21-inch bundles of 6 x 400 grains each symmetrically placed across the die 22 inches apart.

RESULTS

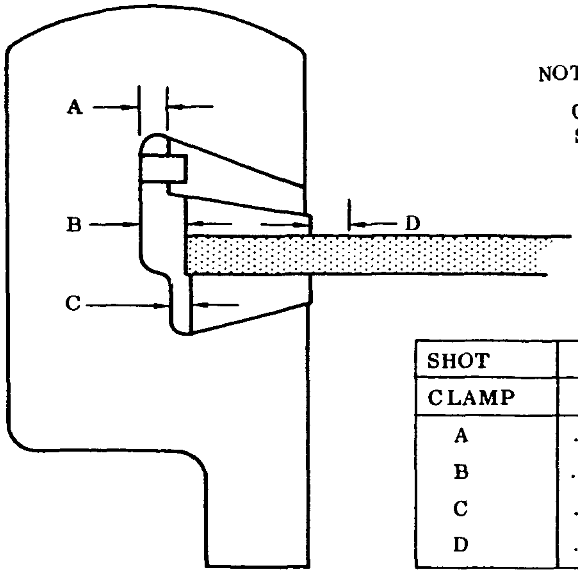
Form - Ogee curve definition was excellent (Figure 13).

Elongation - 2.5 and 3 percent in the flat area that would simulate a trimmed part (Figure 14).

Clamps - held. Three released with normal force (Figure 11).

ANALYSIS

Clamps are capable of withstanding forces required to produce up to 3 percent elongation on .800" 2219-T37 aluminum plate under explosive forming conditions. They release reasonably well. Bolts holding clamps 3 and 4 sheared, probably due to loss of foam or closer proximity of the charge.



NOTE:

Clamp Numbers 1, 2, 3 and 4 as Shown in Figures 12 and 14.

SHOT	1				2			
CLAMP	1	2	3	4	1	2	3	4
A	.44	.505	.350	.290	.44	.520	.350	.300
B	.278	.283	.170	.220	.285	.340	.190	.220
C	.410	.395	.420	.375	.415	.400	.480	.375
D	.150	.110	.250	.140	.160	.110	.250	.145

Figure 11 Movement of Material in the Four Clamps During the Sub-Scale Die Tests

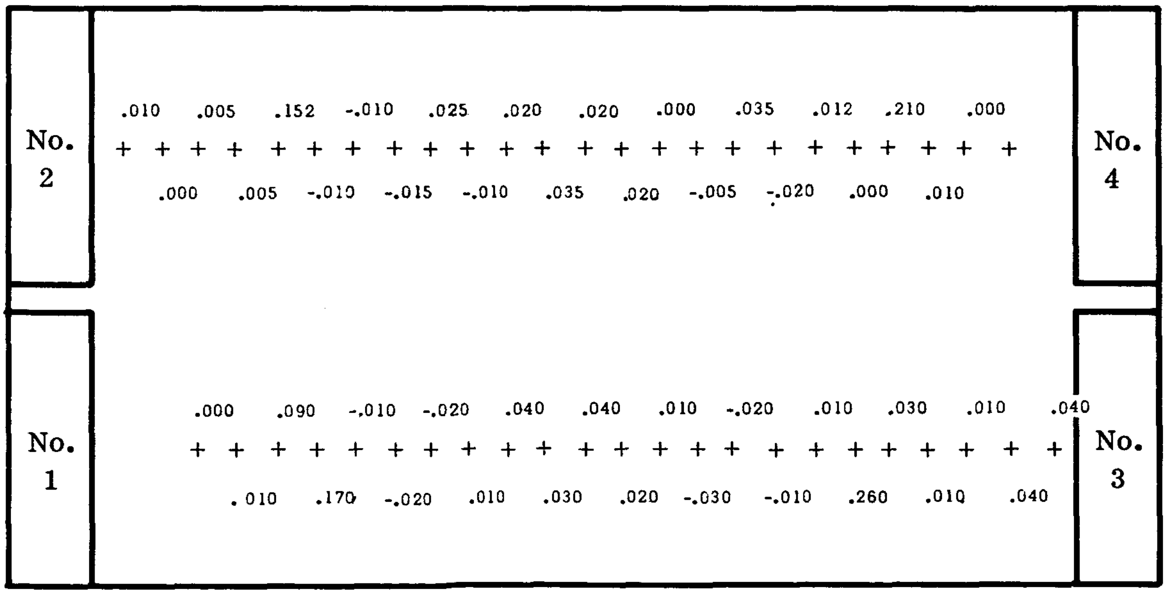


Figure 12 Sub-Scale Die Test Results

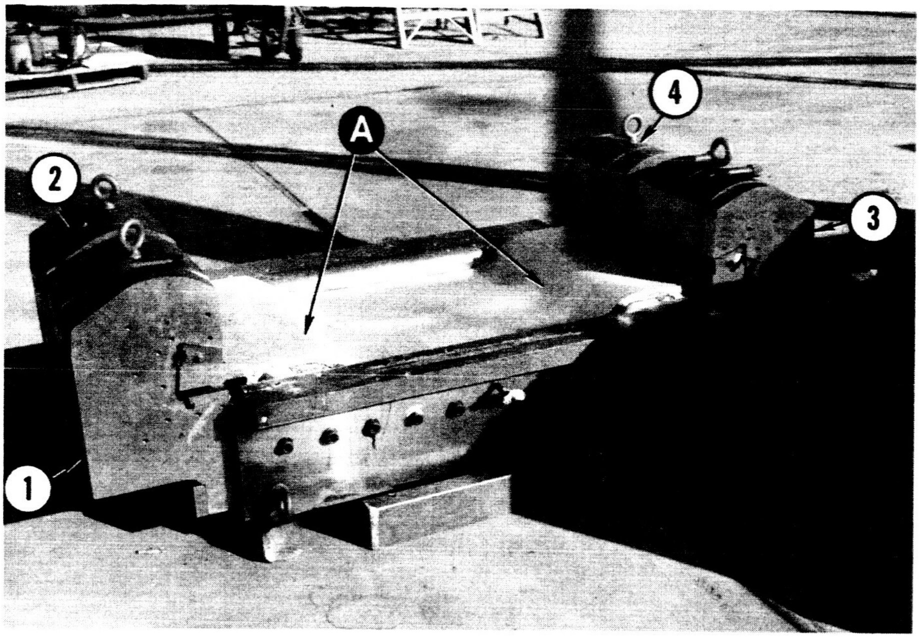


Figure 13 Sub-Scale Die and Four Clamps. Material Shows Good Ogee Curve Definition, A.

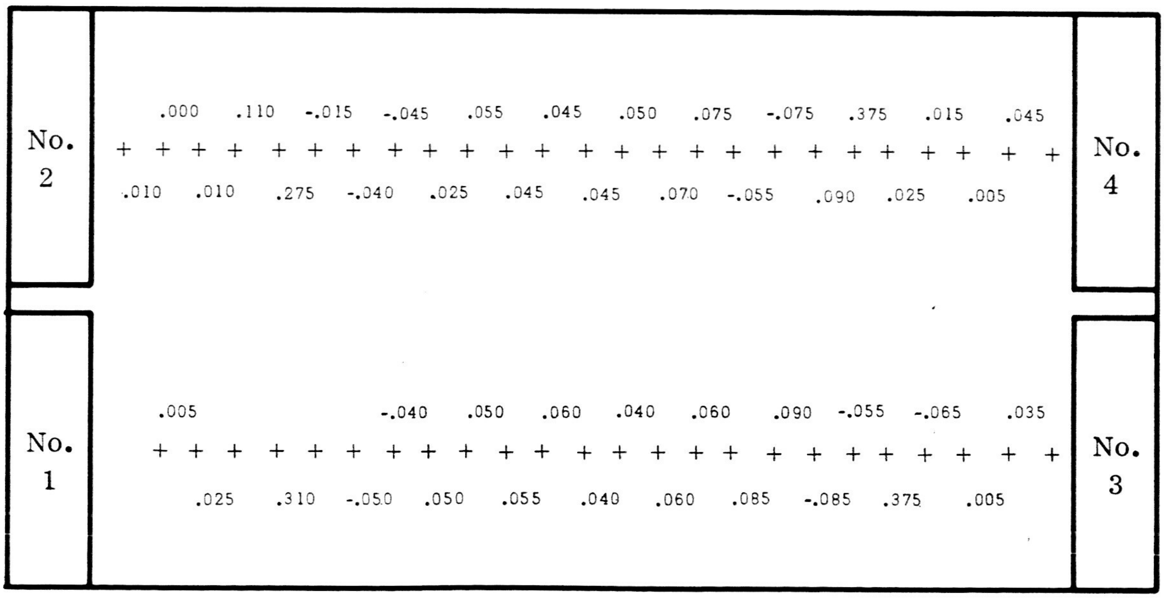


Figure 14 Sub-Scale Die Test Results

RECOMMENDATION

The four clamps should be mounted at the center points of each side of the base die for a jury-rigged shot while the apex die is being modified. Jaw angles and serrations are good and should be used on additional clamps. The wedge angles are good, but provision for more jaw clearance and a better way of driving the cross wedge should be incorporated into the clamp design.

The part from this shot should be chem-milled to determine residual stresses.

CHEM-MILL CHECK

OBJECTIVE

To determine if residual stresses existed in the skin layer of the plate and whether they were due to compression or tension.

PROCEDURE

Preparation - the .800" 2219-T37 aluminum formed plate was identified and cut lengthwise into three strips.

Measurements - of the tab angles relative to the flat bottom were taken before and after chem-milling.

Chem-Milling - .06" was chem-milled off the top of test part C and off the bottom of test part A. The center strip B was left as a control reference which could be related to each of the sides per the identification.

RESULTS

Movement - was toward the chem-milled side in each case, and was greatest at the 3T radius where springback was also most severe (Figure 15).

ANALYSIS

The angular changes shown in Figure 15 prove that residual stress existed. When the restraining layer was chem-milled away, the radii flattened out as expected. The direction of the angular change is controlled by the unwrapping of the larger radius at the bottom of the part and is equal to change in the large radius minus the change in the small radius. The 1°-15° at A2 and 1°-45° at C1 as compared to the 35' change at C2 and A1 ends can only be explained by the lack of uniformity of the 2219-T37 material.

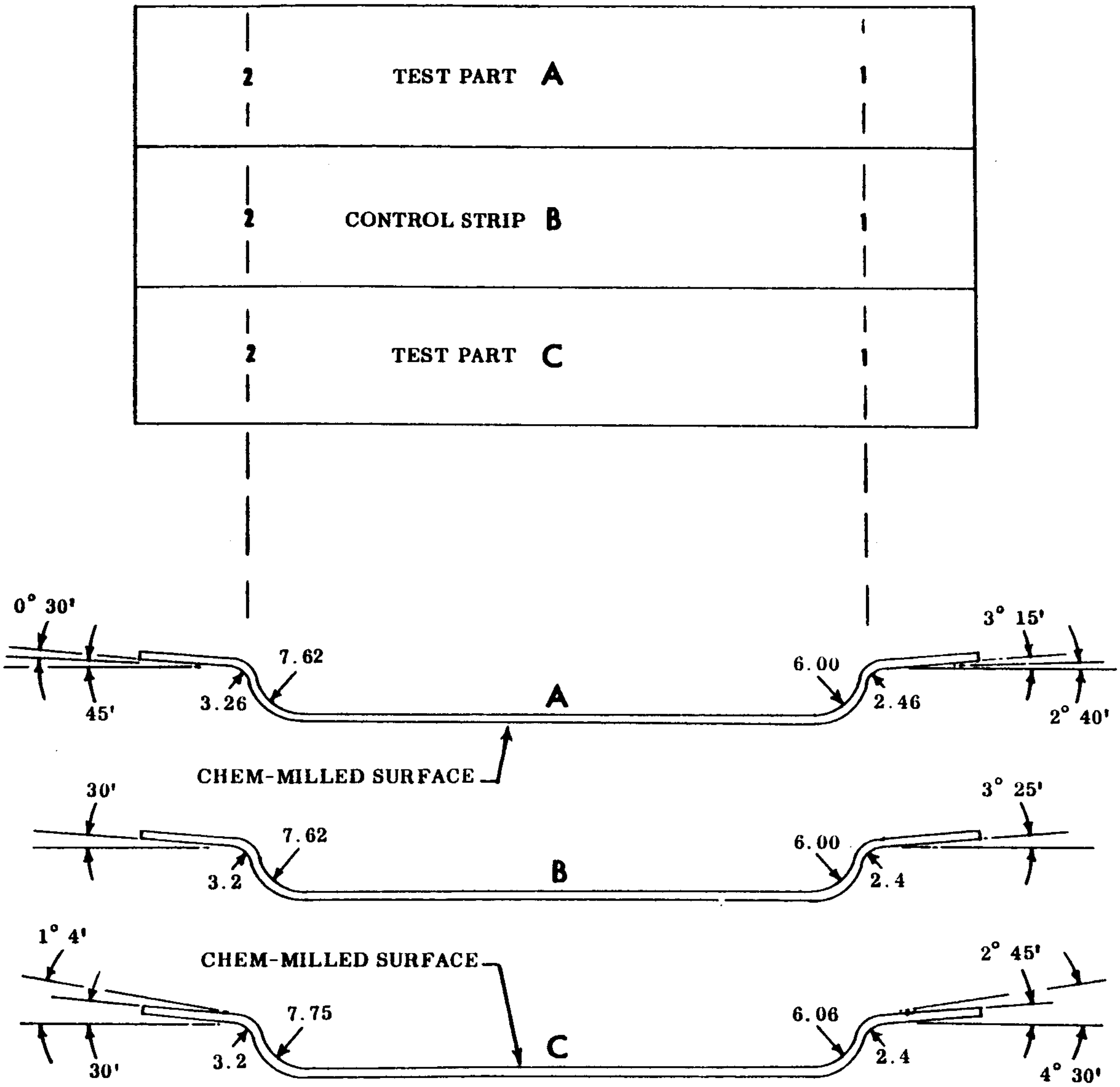


Figure 15 Cross-Section of Formed Material

SUMMARY OF JURY-RIGGED SHOTS

SCOPE

Because these full scale tests were of a preliminary nature they are reported in summary form.

OBJECTIVE

To establish whether balancing the elongation through the use of shims would improve forming. To gain information as to charge magnitude and type, and to gain a feel for the gripping requirements to elongate the material.

PROCEDURE

Four blanks of three thicknesses were run - .297", .420", .661" and .297" respectively.

Blank No. 1 - was formed by using 2.5 pounds of PETN Primacord with a 12-inch standoff under a vacuum of 28 inches of mercury. Despite wrinkling, the forming with use of shims looked promising. All wrinkles were mild enough (Figure 16) to be ironed out by subsequent shots. It was decided that a test on a heavier blank was indicated.

Blank No. 2 - was formed using four shots. The first was a 6.12-pound circular pattern with a 12-inch standoff which formed the part well with some small waviness, but did not take the part to the die. The second shot, two pieces of plastic sheet explosive, one 5" x 10" and the other 2" x 8", was used to take out the most severe wrinkles. The standoff used was 8 inches. The third shot was 1 pound, in two strands of 200 grains per foot, Primacord around the edge with a 12-inch standoff to improve definition. The fourth shot was 3.18 pounds, in an over-all pattern of three rings, of Primacord (Figure 17). Despite a good vacuum, 28.2 inches of mercury, two small flat areas were not quite down to the die indicating trapped air.

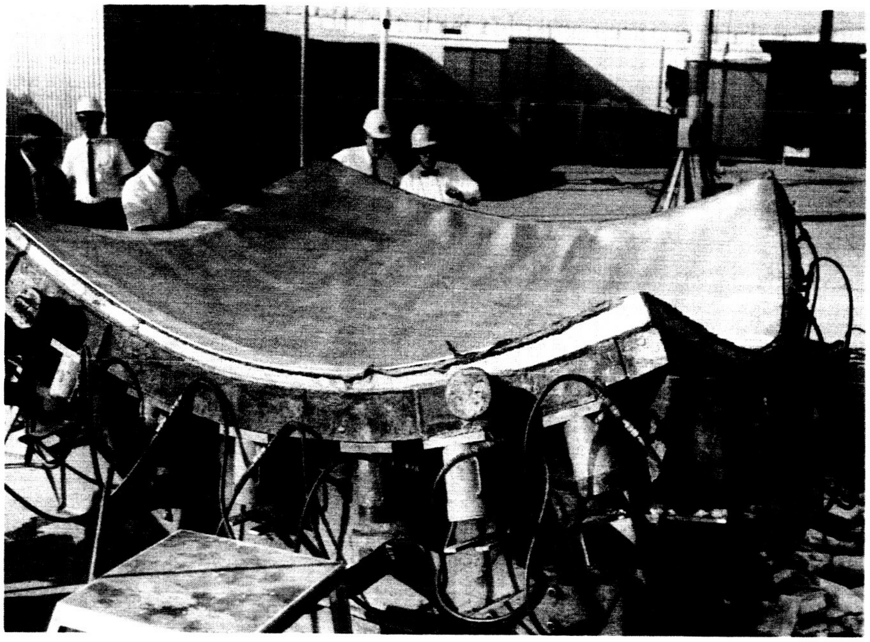


Figure 16 Blank No. 1 Shown Lying in the Die Without Restraint

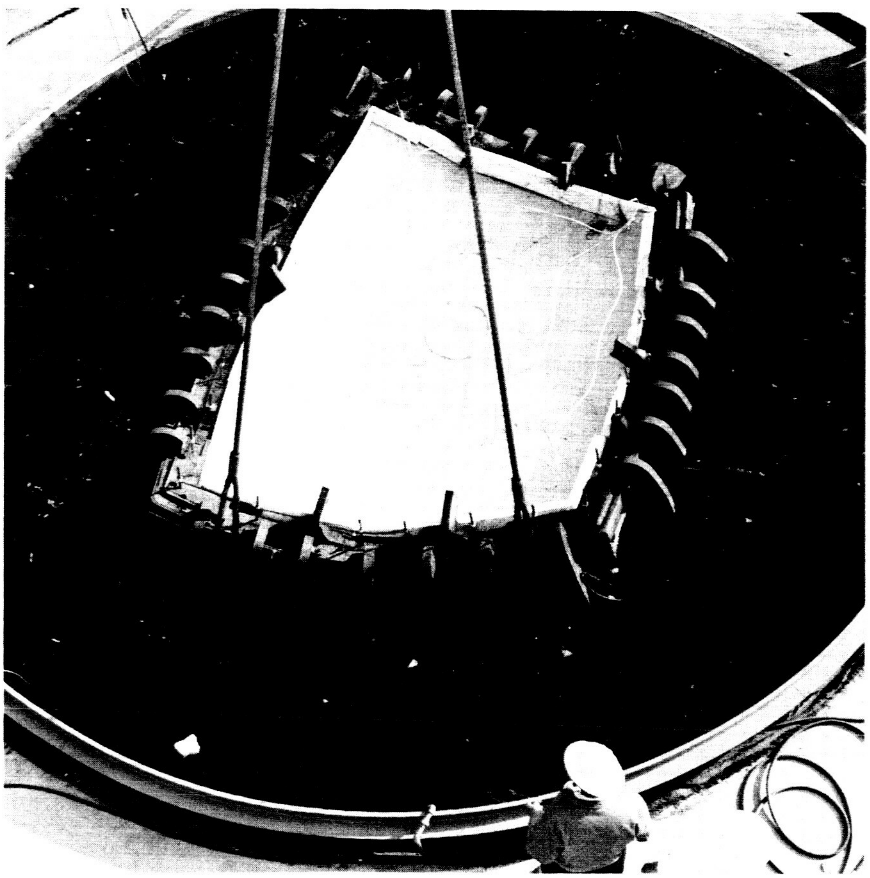


Figure 17 Charge Pattern Used on Blank No. 2

Blank No. 3 - the four stretch press clamps from the sub-scale tests were temporarily rigged at the center of each side of the base die. A tab was welded at the top centerline to increase the width of the blank enough for a full grip by the jaws. The first shot was 9.3 pounds with a 10-inch standoff. All clamps held except the top. The tab broke off at the weld (Figure 18). The form was satisfactorily started with no wrinkles so it was decided to repair the tab and finish form the blank. A second shot of 7.6 pounds with a 12-inch standoff formed the part down to the die (Figure 19) but because the weld breakage robbed the blank of the expected elongation, it was decided to try a .297" blank without adding a tab.

Blank No. 4 - in order to increase the amount of material extending into the jaws the bottom clamp was let-in to a notch in the die edge in accordance with design requirements for Phase III. Blank No. 4 was loaded and clamped as deep into the top and bottom jaw as the 11-foot blank width would allow. A 5.1-pound charge in a two-ring pattern with a 12-inch standoff was used. Vacuum was 28.2 inches of mercury.

RESULTS

Blank No. 1 - laid down to the die edge (Figure 16) when the draw ring was removed despite low elongation of .35 percent. This elongation could have beem improved by a second hit.

Blank No. 2 - had better elongation - 76 percent. Wrinkling was less severe than experienced before the addition of the shims. Wrinkles were in the form of waviness and were easily removed. The part definition was good when held by the draw ring. It appeared to be down to the die except in two small flat spots. The edge of the part pulled away from the die when the draw ring was removed.

Blank No. 3 - the welded tab broke at the weld. All clamps gripped and held. Indentation of the jaw serrations into the material was good (Figure 20). The average elongation after the second shot was .95 percent. The part definition was good except for a flat area in the center. The part sprung away from the die edge when released, especially along the bottom.

Blank No. 4 - the bottom clamp failed to grip causing the right side tab to start to fail. A large wrinkle formed at the bottom center of the blank.

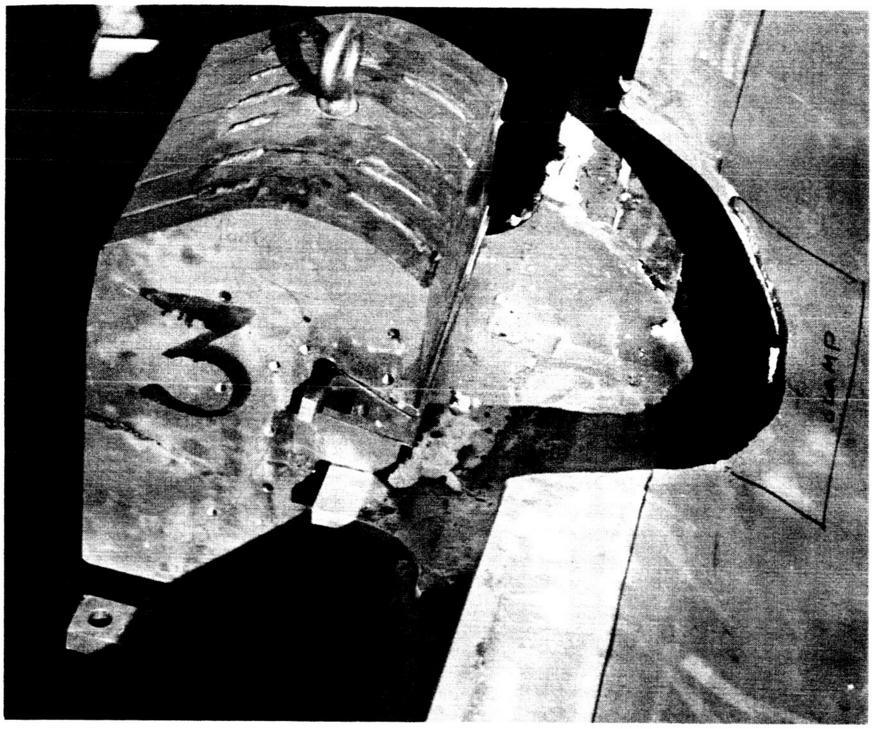


Figure 18 Weld Failure at Tab on Blank No. 3

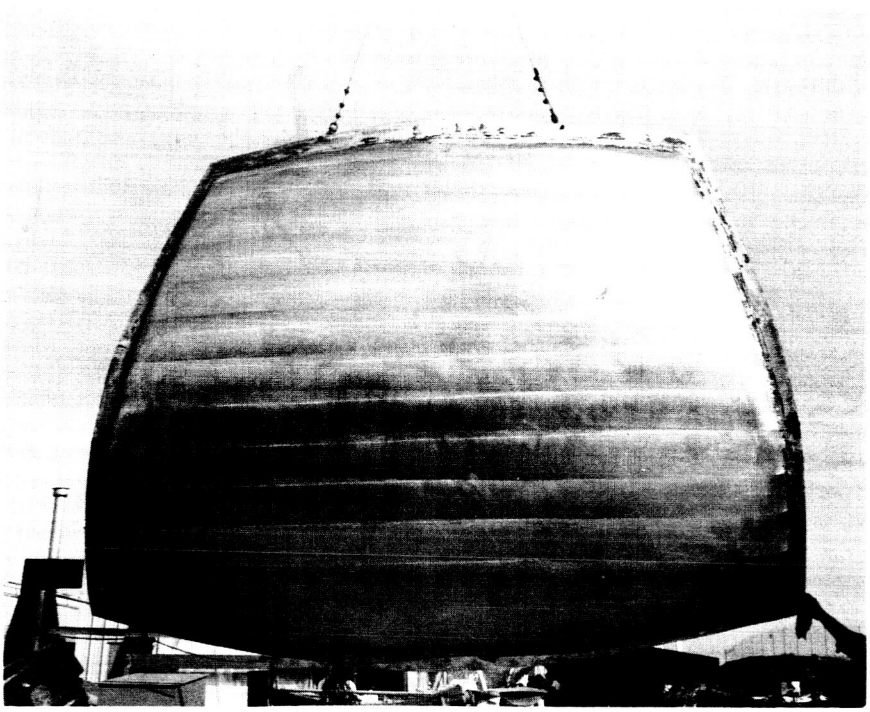


Figure 19 Final Formed Part Blank No. 3

ANALYSIS

The shims improved forming because the material moved in more uniformly from the edges. Therefore, this concept appears valid. 60 tons per jack was inadequate holding force to produce elongation when used with the double-faced sand paper. Despite the failure of the tab, the stretch press clamps proved their value on Blank No. 3 by increasing the elongation from .76 to .95 percent. The failure of the clamps on Blank No. 4 was due to inefficient tab material in the jaw. This allowed the jaws to crush the outer edge of the aluminum which in turn allowed the upper jaw to tip so that it could no longer grip the material (Figure 21). If this could have been anticipated, it could have been prevented by insertion of a filler strip to support the heel of the jaw. The flats indicate entrapped air bubbles.

The curved edge of the die aggravates the springback condition because the edge material is eccentrically loaded, instead of acting like a beam as the blank edge under a draw ring normally does in draw operations. The charge pattern appears to give symmetrical forming and the method of calculating appears to be valid.

RECOMMENDATION

The shim concept should be incorporated into both the base and apex dies using steel. The gripping effect of the 60-ton clamps and draw ring should be increased by the addition of serrations to the outer surface of the shims similar to the jaw serrations. The vacuum vent area should be increased and preliminary light shots should be used before the final hit brings the part down to the die. This procedure will reduce the volume of air so that little will be present at the time of the final shot to cause bubbles.

Both gridded and circular charge patterns should be used and strain guages used to help analyze explosive effects.

Five stretch press clamps should be added to the apex die and nine to the base die. They should be located so as to add support primarily to the centers of each side.

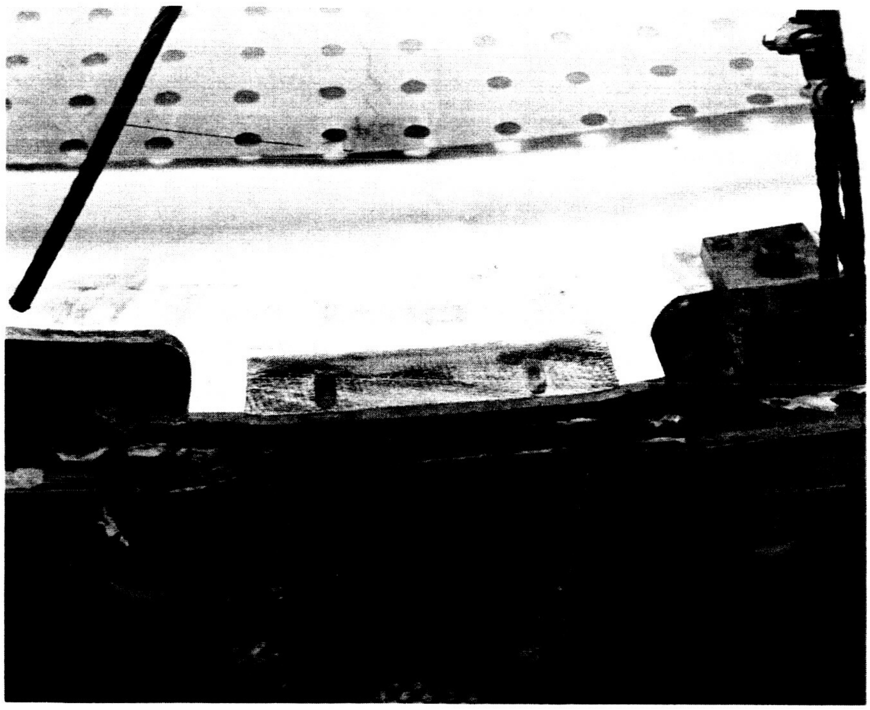


Figure 20 Serration Pattern Indented Into Material

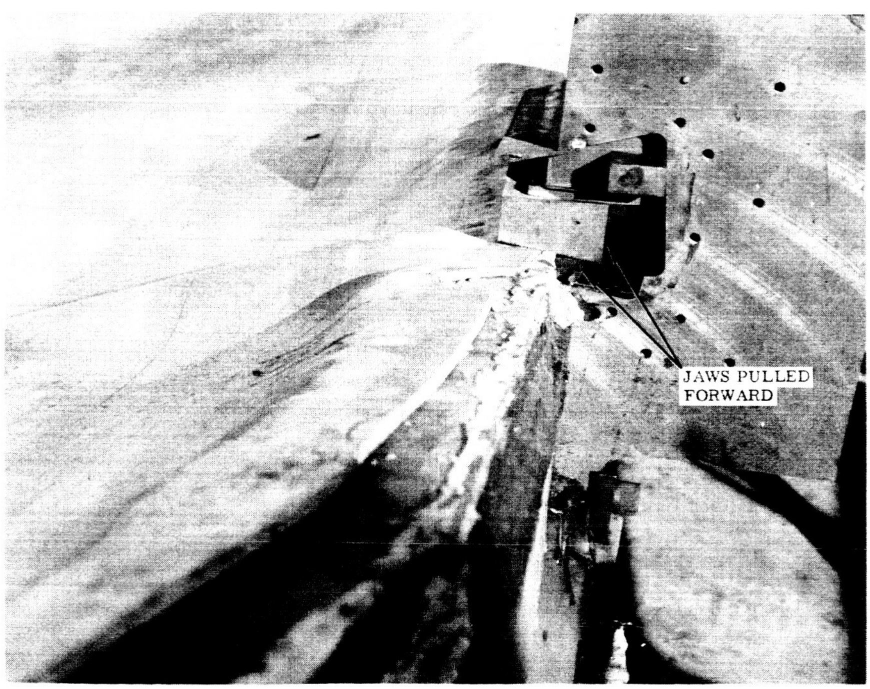


Figure 21 Jaw Failure Due to Crushing of Tabs